EDGEWOOD ARSENAL

TECHNICAL REPORT

EATR 4029

Cathodic Cleaning of Aluminum Alloys for X-Ray-Clear Welds

by

F. B. Gurtner
J. C. Williams

October 1966

Preproduction Evaluation Division
Technical Support Directorate
US ARMY EDGEWOOD ARSENAL
EDGEWOOD ARSENAL, MARYLAND 21010

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Project 1X543603D118

Preproduction Evaluation Division
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FOREWORD

The work described in this report was authorized under Project 1X543603D118, GB Warhead for LANCE Missile (E27) (U). The work was started in February 1965 and it is continuing.

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Acknowledgment

The authors acknowledge the assistance of Mr. William Davis, Field Evaluation Division, in performing the initial colored photographic study.

DIGEST

Cathodic cleaning was studied as a method of cleaning aluminum alloys for welding in which X-ray quality is desired. Cathodic cleaning, teste on 6061 aluminum strips and evaluated by welding with the automatic dc tungsten-arc process, was found to be an improvement over previous cleaning methods. The use of cathodic cleaning reduces to a minimum any smut produced by welding.

The photographic results of these tests show that the cleaning process can be reduced from the level of an art to that of a repeatable, scientific process. These photographs define the lack of quality control previously exercised either on the sheet material or on an extruded part. Control will have to be established over surface pits, inclusions, and miscellaneous configurations, which are a trap for hydrates, foreign elements, and cutting and drawing compounds.

It is neither economical nor reliable to attempt to induce greater control over welding and chemical compatibility unless this control is extended to the manufacturing processes producing the initial item.

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CATHODIC CLEANING OF ALUMINUM ALLOYS FOR X-RAY-CLEAR WELDS

I. INTRODUCTION.

The purpose of these experiments was to reduce the process of cleaning aluminum alloys for welding from the level of an art to that of a repeatable, scientific process.

The cleaning of aluminum alloys for welding, in which X-ray quality or a helium leak test is required, is an inherent problem in the welding industry. The problem becomes greater when chemical compatibility is considered. Research and analysis of chemical reactions have shown that, if an X-ray-clear weld can be produced without extra cleaning, the compatibility problem is solved. Compatibility is defined here as no reaction or pressure buildup during storage.

Tests to date have shown that the ability to produce an X-ray-clear weld depends on the removal of $Al_2O_3 \cdot H_2O$. Under the welding-arc temperature of 10,000°F or more, the H^+ ion is disassociated from the $Al_2O_3 \cdot H_2O$ complex and becomes 100% soluble in the solidus aluminum alloy. The solubility of the H^+ ion changes when the molten aluminum alloy cools, whereupon molecules of hydrogen are formed that migrate to the last point of freezing to form porosity, which aids in the formation of cracks due to stress concentrations set up by the H^+ ions when they are compressed into molecules. The $Al_2O_3 \cdot H_2O$ complex is termed a hydrate to differentiate it from Al_2O_3, which corresponds to work done at MIT under a NASA contract in 1958.

The usual procedure for determining if a material is chemically clean involves the production of a "water-break-free surface." There is no relationship here between a water-break-free surface and an X-ray-clear weld because, in either instance, the $Al_2O_3 \cdot H_2O$ must be removed, and it can only be eliminated by mechanical means.

The usual method of cleaning after the standard chemical cleaning is to mechanically scrape and drawfile all surfaces subjected to fusion. To circumvent the excessive cost of mechanical or manual cleaning, cathodic cleaning of aluminum alloys has been investigated to determine its feasibility, procedure, wattage, and weld reaction.

II. EXPERIMENTATION.

Sample No. 1 (appendix, figure A1) was the preliminary test piece. (All figures, A1 through A39, are in the appendix.) The approach followed after sample No. 1 was to determine the required voltage, current, and current

direction, and the distance between the anode and the cathode. Anodic cleaning (figure A2) proved to be of no value because, by using a stainless-steel cathode, the aluminum sample had received a film of chromium oxide. The weld bead showed a zero flow angle, and the resulting stress flow would be detrimental to the weldments.

Samples No. 3 through No. 15 (figures A3 through A13) were cathodically cleaned in a progressive manner to evaluate the effect of different anodes, amperages, voltages, times, distances, and followup solutions. The reactions of the above variables, in both cleaning and welding operations, are shown in tables I and II, together with observations made throughout the development stages.

The angle of flow with reference to the filler metal being used showed that the stress-flow pattern of aluminum weldments can be changed by proper cleaning. Normally, the wetting angle of any weld made on aluminum is quite steep, producing a closed stress pattern. With the long wetting angle of 45° (estimated), the stress-flow angle opens up with a resulting gain in fatigue life.

The use of additional solutions for the samples in figures A10 through A13 provides a cleaning process that does not require manual steps. Further work will encompass larger samples cleaned by cathodic methods and butt-welded together with gas-tungsten arc dc, gas-tungsten arc ac-balanced wave, and gas-metal arc, using fully automatic methods of welding.

The photographs in the appendix illustrate the cleaned surface of each sample in conjunction with automatic and manual welding. Automatic welding of the samples showed an unusual change when the weld bead passed the cleaned section of the plate into the as-received section, in that the weld-bead width increased in the as-received area on both the top and bottom surfaces.

During automatic dc welding with a voltage-controlled head, the sensitivity of the welding head changed when the arc encountered the unclean surface. The welding head produced a stitching effect in a vertical oscillating direction due to the bombardment of the tungsten electrode by foreign material. The vertical oscillation refers to the up and down movement of the voltage-controlled torch due to the metallic bombardment of the gaseous plasma and the tungsten electrode by ionized elements. The analysis of welds made on strips by the automatic dc tungsten-arc process showed that an exothermic reaction occurs under the welding arc, which allows a greater input of heat to the material than had been calculated. To maintain a constant heat input, the surfaces and joint edges must have a controlled cleanliness for the heat input to be calculated correctly.

Table I. Conditions and Results of Cathodic Cleaning of Aluminum Alloys for Welding

Sample No.	Material	Electrolyte a/	Cathode (−)	Anode (+)	Time	Electrolysis			Rinse	Surface	Solution color
						Amps	Volts	Distance			
					sec			in.			
1	2024	b/	—	—	240	—	—	—	Tapwater	Etched	Clear
2	2024	b/	Stainless steel	2024	120	2	10	1.5	Tapwater	Plated	—
3	2024	b/	2024	Stainless steel	50	27	7	1.5	Tapwater	Cleaned	Light brown
3 c/	2024	b/	2024	Stainless steel	50	45	10	1.5	Tapwater	Cleaned	Light brown
4	6061-T4	b/	6061-T4	Stainless steel	50	47	8.4	1.5	Tapwater	Cleaned	Light brown
5	6061-T4	b/	6061-T4	Stainless steel	60	47 - 54	7.6 - 8	1.5	Tapwater	Cleaned	Light brown
6	6061-T4 Extrusion	b/	6061-T4	Stainless steel	60	54	7.6	0.5 - 1	Tapwater	Cleaned	Light brown
7	6061-T4 Extrusion	b/	6061-T4	Stainless steel	60	54	7.6	0.5 - 2	Tapwater	Etched	Green-black
7 c/	6061-T4 Extrusion	b/	6061-T4	Stainless steel	240	58	7.4	0.5 - 2	Tapwater	Etched	Green-black
8	6061-T4	d/	6061-T4	Platinum	60	45	8	1.75	Tapwater	Etched	Clear
9	6061-T4	d/	6061-T4	Platinum	120	40 - 42.5	8.3 - 8.4	1.75	Tapwater	Cleaned	Clear
10	6061-T4	d/	6061-T4	Platinum	75	40	8.4	1.75	Tapwater	—	—
10 c/	6061-T4	d/	6061-T4	Platinum	105	42	8.3	1.75	Tapwater	Cleaned	Clear
11	6061-T4	d/	6061-T4	Platinum	—	39 - 45	8.0 - 8.4	1.5	Tapwater	Light etching	Clear
12 e/	6061-T4	d/	6061-T4	Platinum	90	54	9.6	1	—	Smut removed, passivated	Clear
13 f/	6061-T4	d/	6061-T4	Platinum	90	62	9.4	1.25	—	—	Clear
14 g/	6061-T4	d/	6061-T4	Platinum	90	58	9	1.25	Tapwater	Smut removed, passivated	Clear
15 g/	6061-T4	d/	6061-T4	Platinum	90	58	9	1.25	Tapwater	Smut removed, passivated	Clear

a/ Sulfuric acid was selected as a suitable electrolyte because of its metallurgical use as a macroetchant.

b/ 300 ml of H_2O and 60 ml of H_2SO_4.

c/ The sample above was reprocessed.

d/ 700 ml of H_2O and 188 ml of H_2SO_4.

e/ A solution of 60% H_2O and 40% HCl was added after electrolysis and rinse.

f/ A solution of 60% H_2O and 40% HCl was added after electrolysis and rinse, followed by a scrub-warm rinse.

g/ A solution of 60% H_2O and 40% HCl (room temperature, 48 sec) was added after electrolysis and rinse, followed by a tapwater rinse, by a solution of 50% H_2O and 50% HNO_4 (room temperature, 1-1/2 min), and by another tapwater rinse.

Table II. Conditions and Results of Welding of Aluminum Alloys

Sample No.	Automatic/ Manual	Inert gas	Filler rod	Amps	Volts	Speed	Tungsten extension	Type of current	Wetability	Flow angle	Surface	Remarks
						in./min	in.					
1	M	Argon-helium	4043	–	–	–	–	acWB*	Excellent	45°	White	Attraction for filler rod; no sign of dirt without filler rod
2	M	Argon	4043	–	–	–	–	acWB	None	None	Plated	Resistance for filler rod; surface shows foreign metal, backside shows film
3	M	Argon	4043	–	–	–	–	acWB	Excellent	45°	White	Attraction for filler rod; no sign of dirt without filler rod
7	M	Argon	4043	–	–	–	–	acWB	Good	30°	Tarnished white	Start shows smut; no welding problem with or without filler rod
8	A	Helium	None	50	17.8	16	3/16	dcSP**	Excellent	None	Clear to brownish	Weld-bead width changes in noncleaned area; machine chatters
9	A	Helium	None	56	17.8	16	3/16	dcSP	Poor	None	Black smut	Weld-bead width increases in noncleaned area
10	A	Helium	None	56	17.8	16	3/16	dcSP	Poor	None	Gray-blue smut	Action not satisfactory
11	A	Helium	None	56	17.8	16	3/16	dcSP	Good	None	Gray to clear	Weld-bead appearance improved
13	A	Helium	None	30	17.8	16	3/16	dcSP	Excellent	None	Light gray to clear	Weld bead is clear; width increases in noncleaned area; weld-bead action is good
14	A	Helium	None	30	17.8	16	7/16	dcSP	Excellent	None	No smut, clear	Weld bead increases in cleanliness; flow of metal surface increased
15	A	Helium	None	30	17.8	16	7/16	dcSP	Excellent	None	No smut, clear	Weld bead is good; flow of metal is good; control is improved; less debris

*WB = wave balance.
**SP = straight polarity.

The lack of smut or ionized, metallic particles deposited adjacent to the weld or on the weld surface indicates a lack of exothermix reactions.

The photographs in figures A14 through A34 were taken in color and nagnified 10 times after standard chemical cleaning of the 6061 aluminum samples and prior to the initiation of the cathodic cleaning. The purpose was to determine if any problems existed in cleaning 6061 aluminum that could cause a change in surface tension and welding conditions. These photographs show that a wide range of chemical compounds exists on the surfaces. Colorimetric chemistry and interpolation would have to be used to interpret these compounds. Interpretations have not been attempted to date, but may be forthcoming.

Figures A35 through A39 show the effect of adverse conditions when weldments that were submitted to storage tests reacted with the weld (parent metal and filler metal) and with the parent material. The samples in figures A35, A36, and A38 show that conditions had accelerated to the point that a hole was eaten from the inside of the E-139 bomblet through the weld. This reaction centered around foreign matter that was believed to be ferric or ferrous oxide. The samples in figures A37 and A39 show that reactions had taken place outside the heat-affected zone of the weld area, which is pure parent metal.

Further work should be undertaken in the area of cleaning for welding and compatibility to establish a firm process for the production of agent containers and X-ray-clear welds.

III. CONCLUSIONS.

The photographic results of these tests show that the cleaning process can be reduced from the level of an art to that of a repeatable, scientific process. These photographs define the lack of quality control previously exercised either on the sheet material or on an extruded part. Control will have to be established over surface pits, inclusions, and miscellaneous configurations, which are a trap for hydrates, foreign elements, and cutting and drawing compounds.

It is neither economical nor reliable to attempt to induce greater control over welding and chemical compatibility unless this control is extended to the manufacturing processes producing the initial item.

APPENDIX

FIGURES

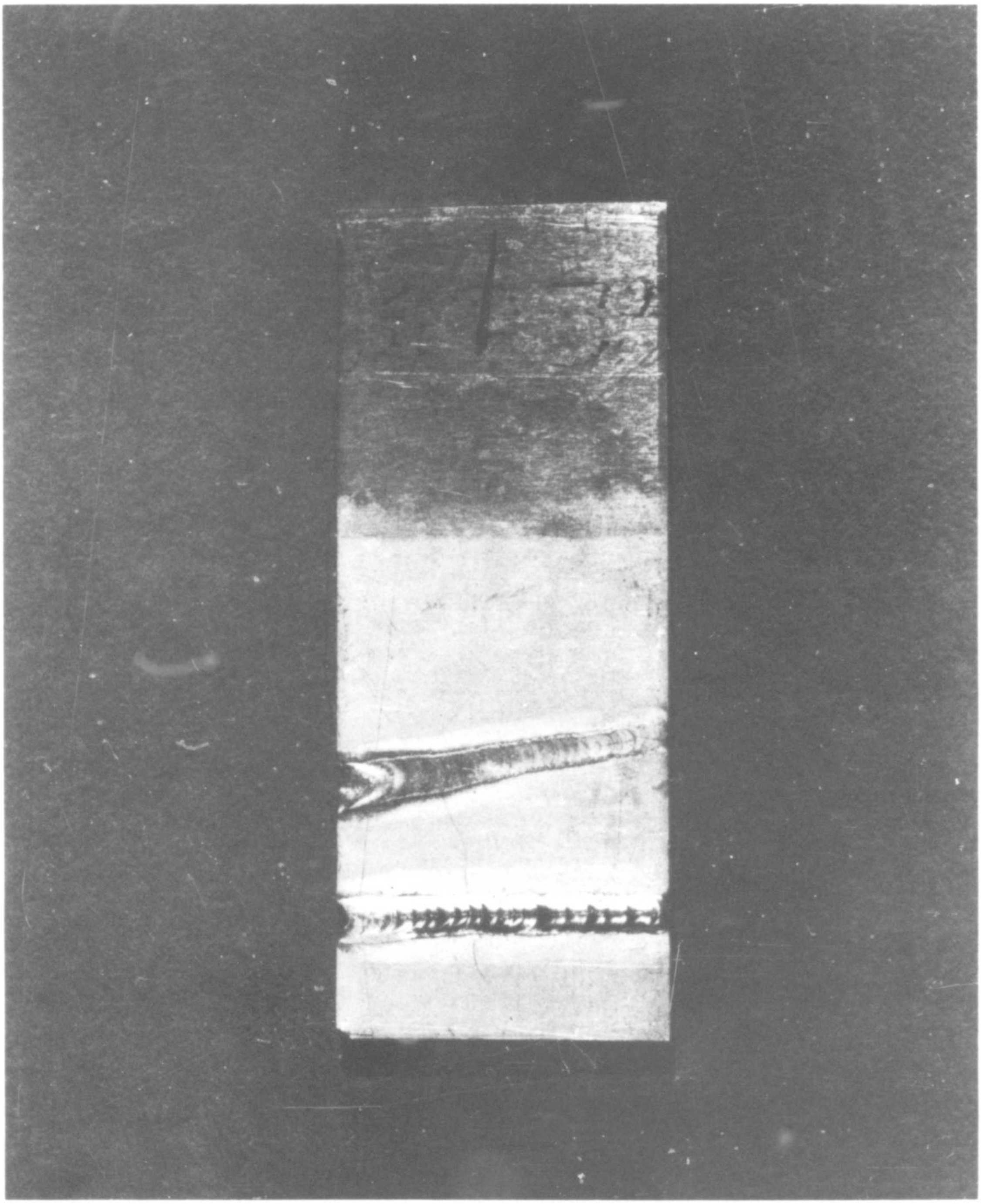

Figure A1.   Sample No. 1

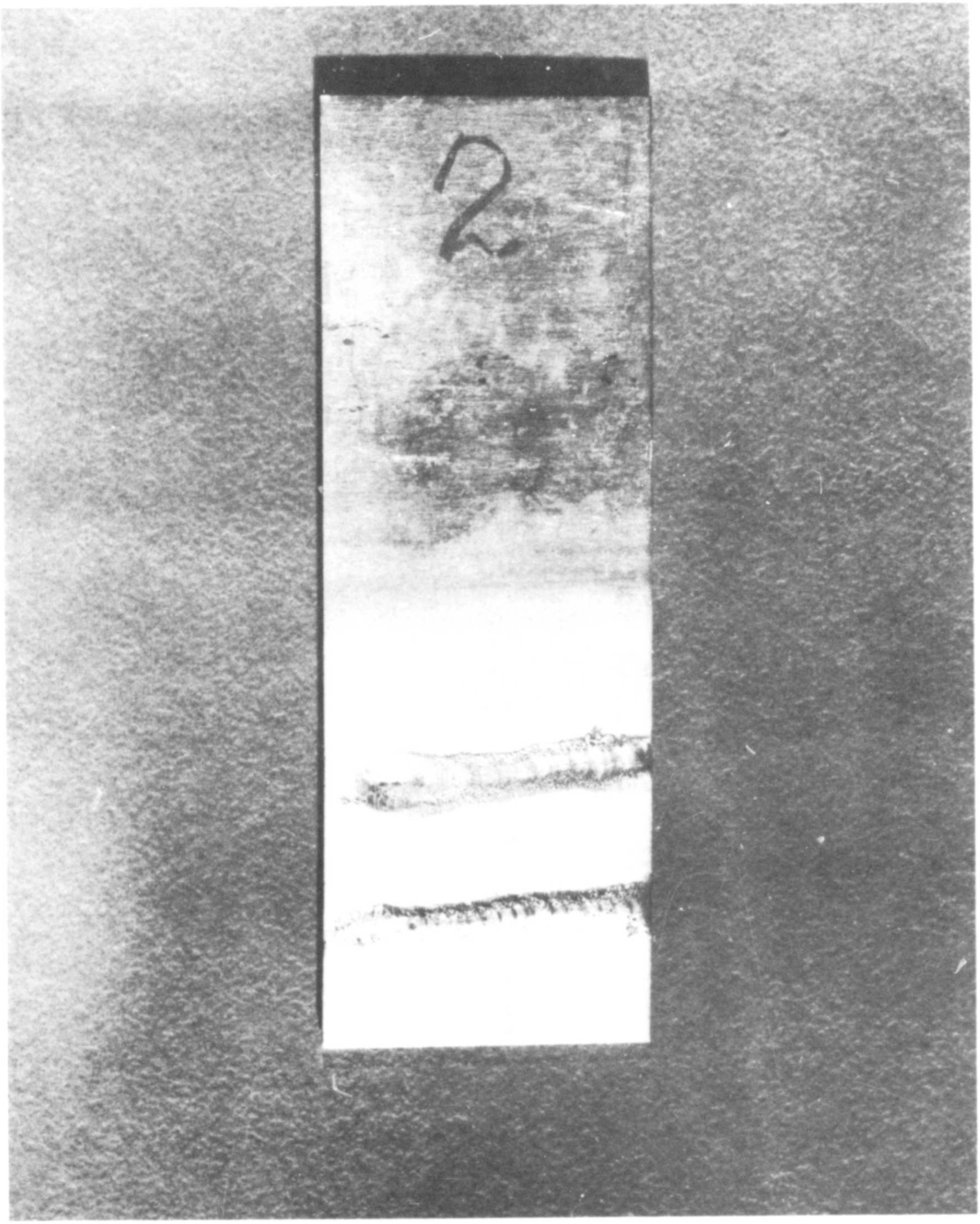

Figure A2. Sample No. 2, Anodically Cleaned

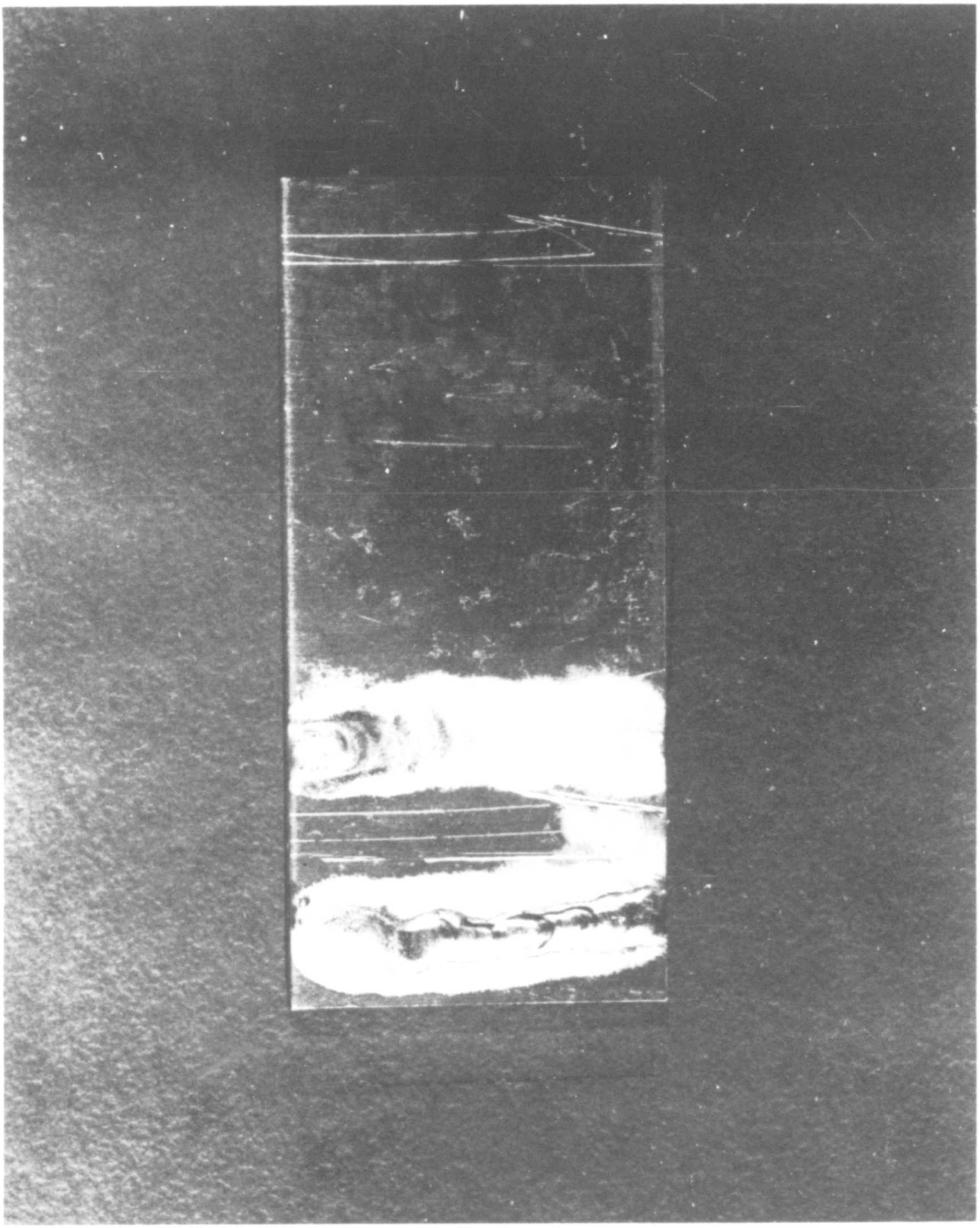

Figure A3. Sample No. 3

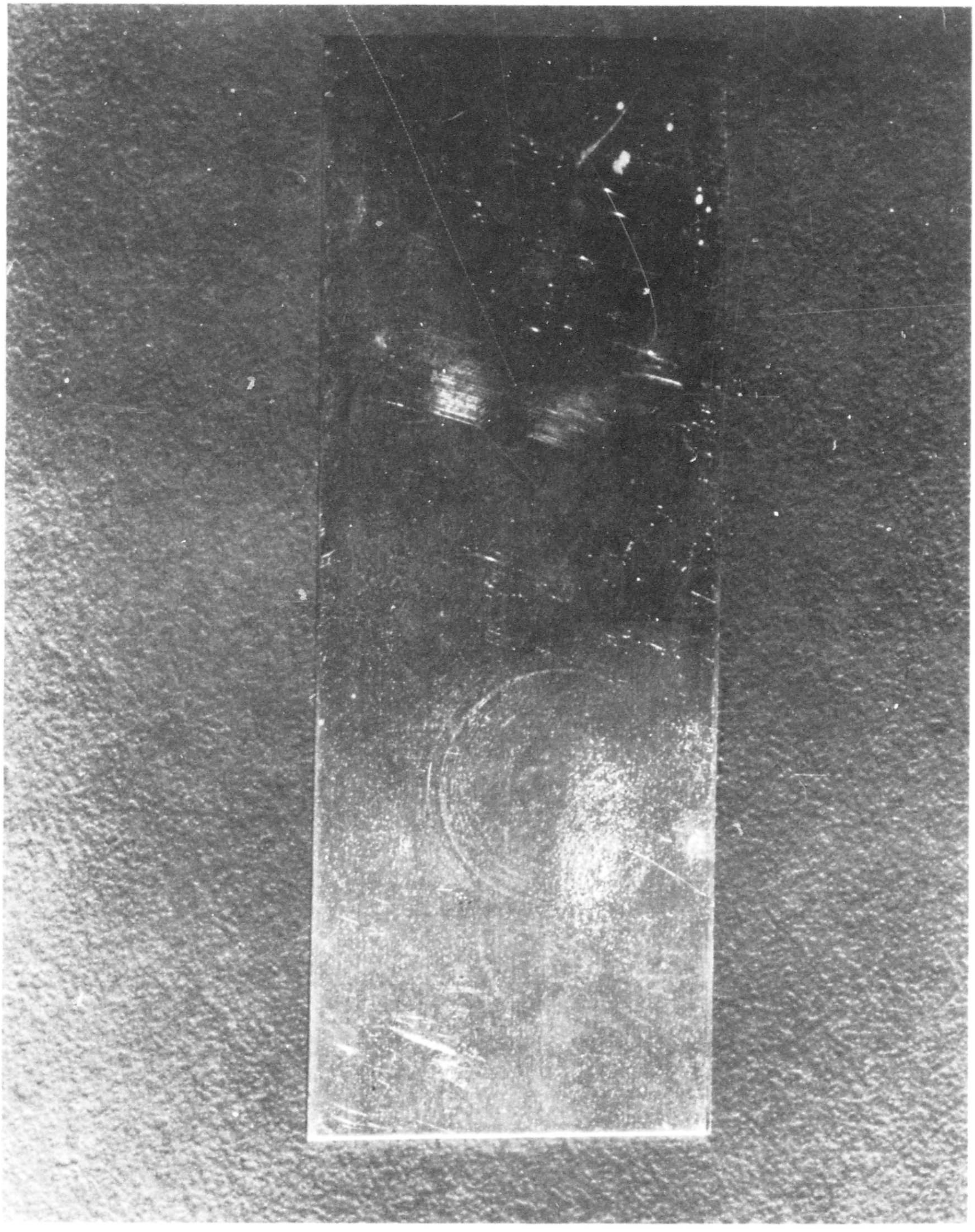

Figure A4. Sample No. 5

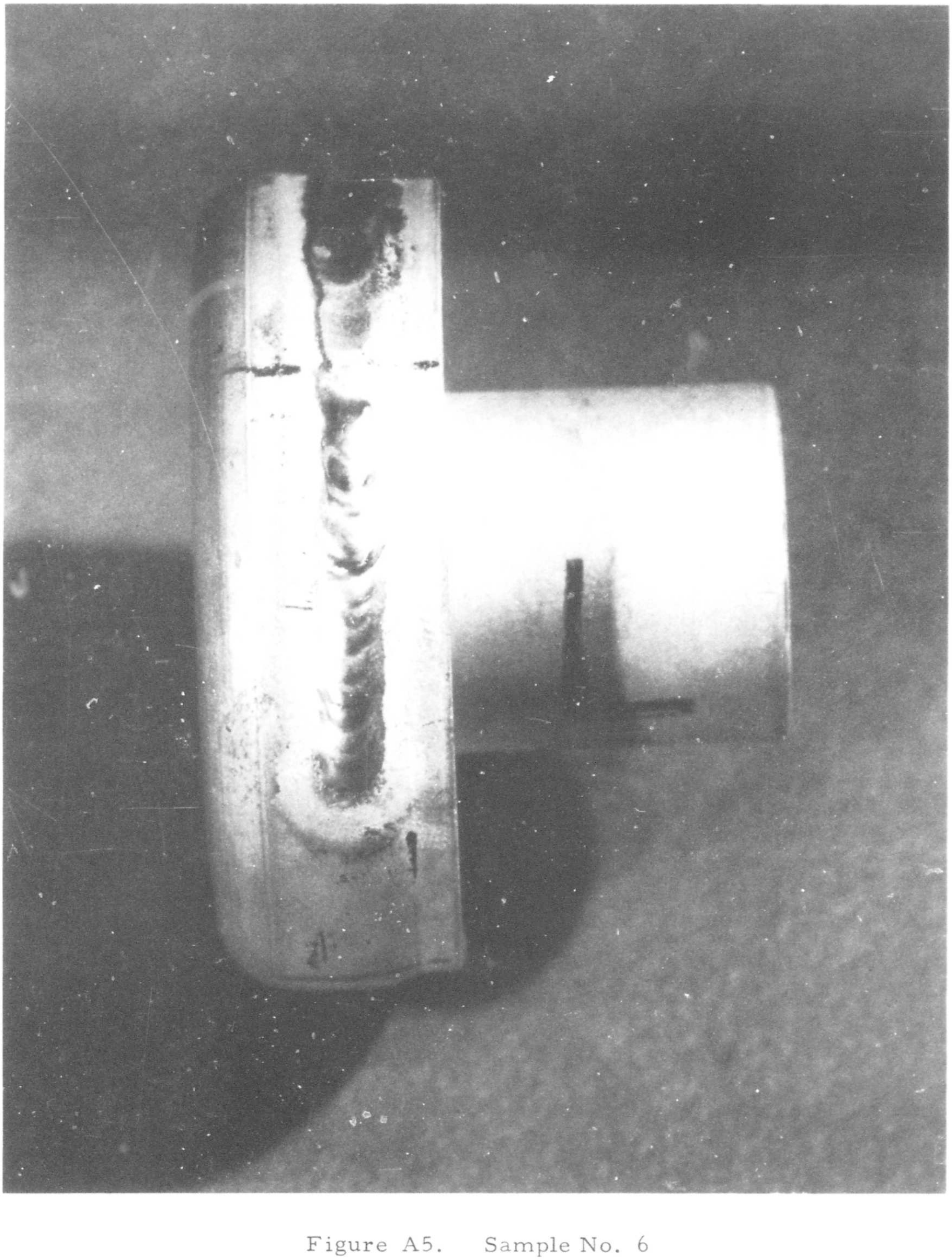

Figure A5. Sample No. 6

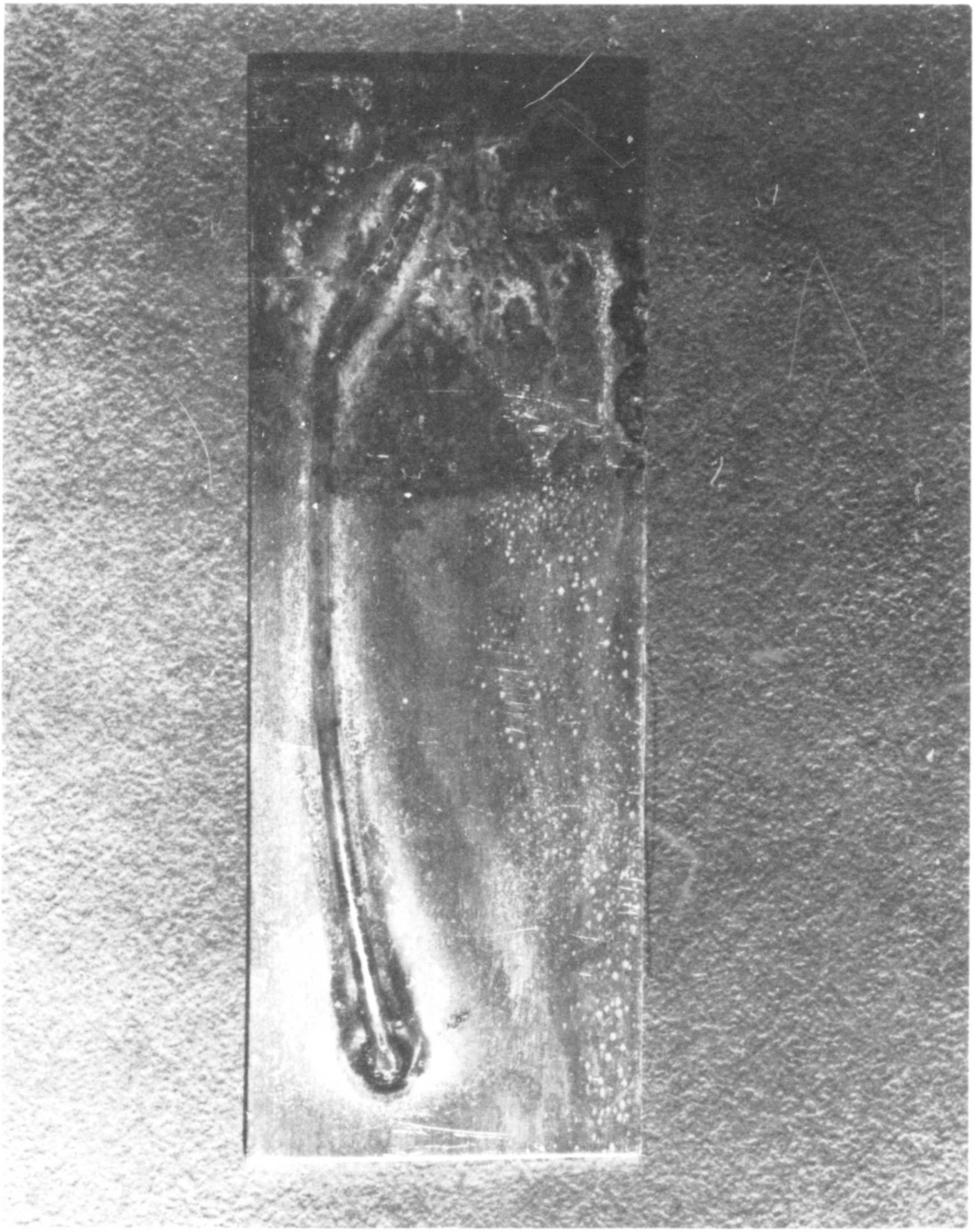

Figure A6. Sample No. 8

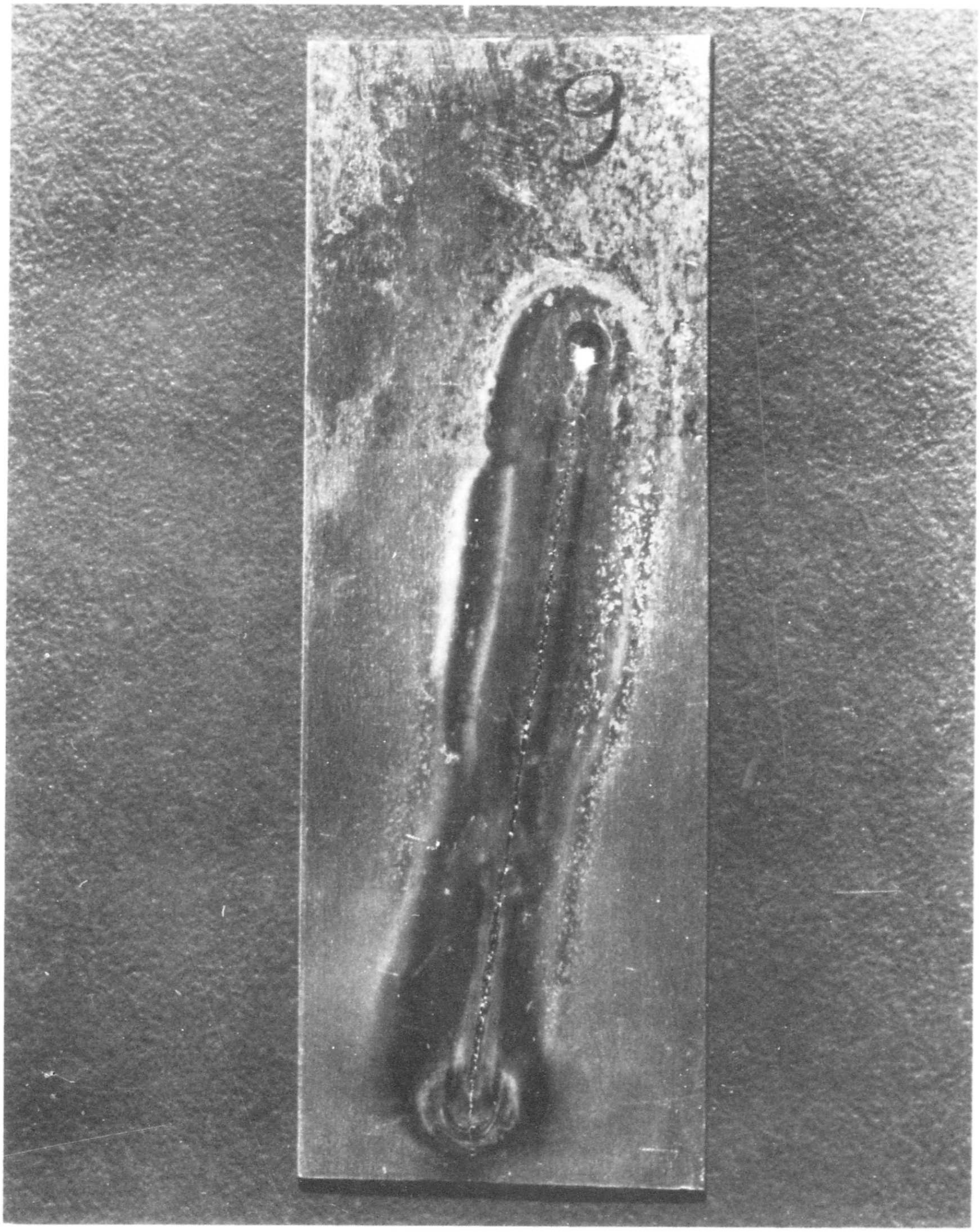

Figure A7. Sample No. 9

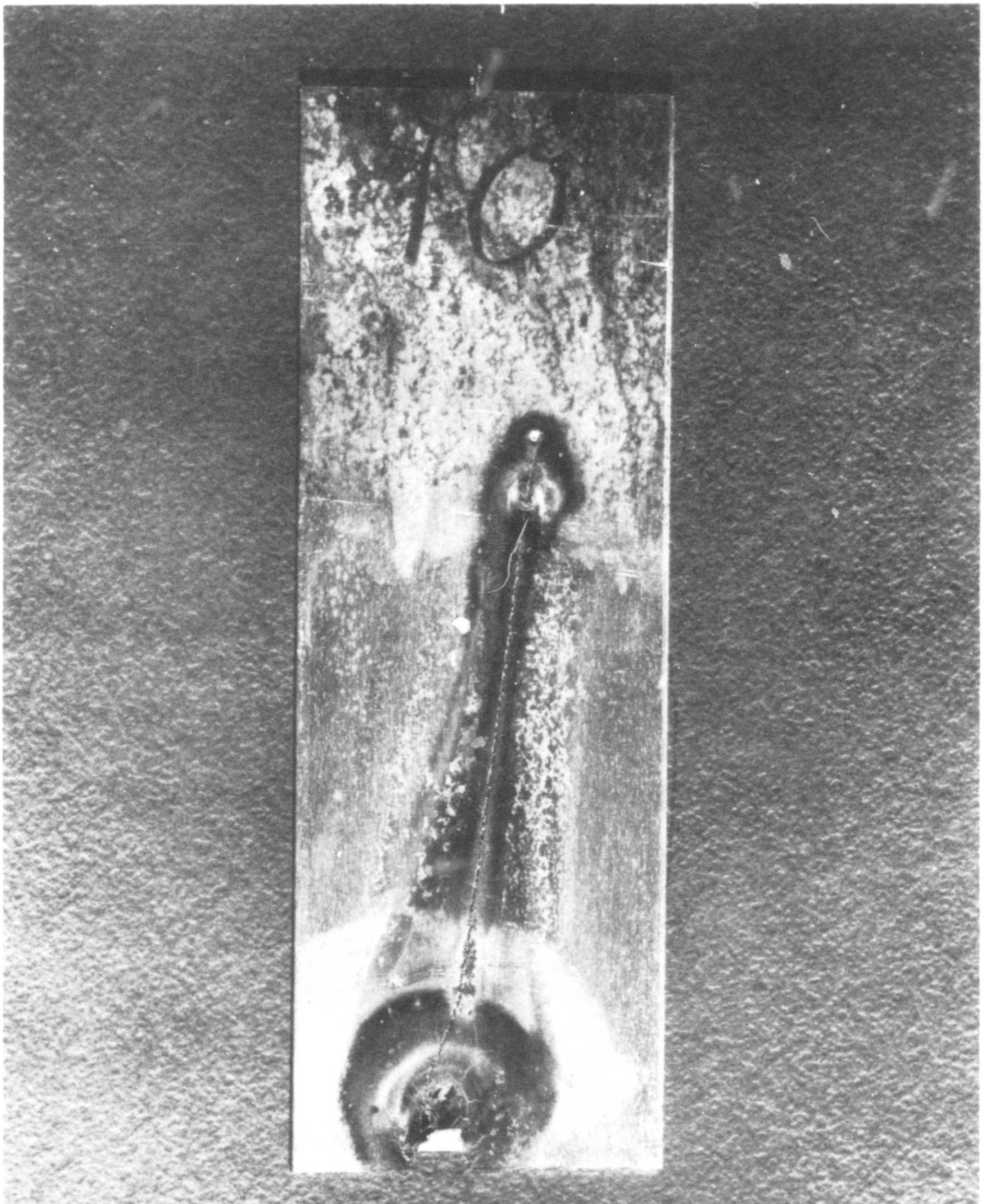

Figure A8. Sample No. 10

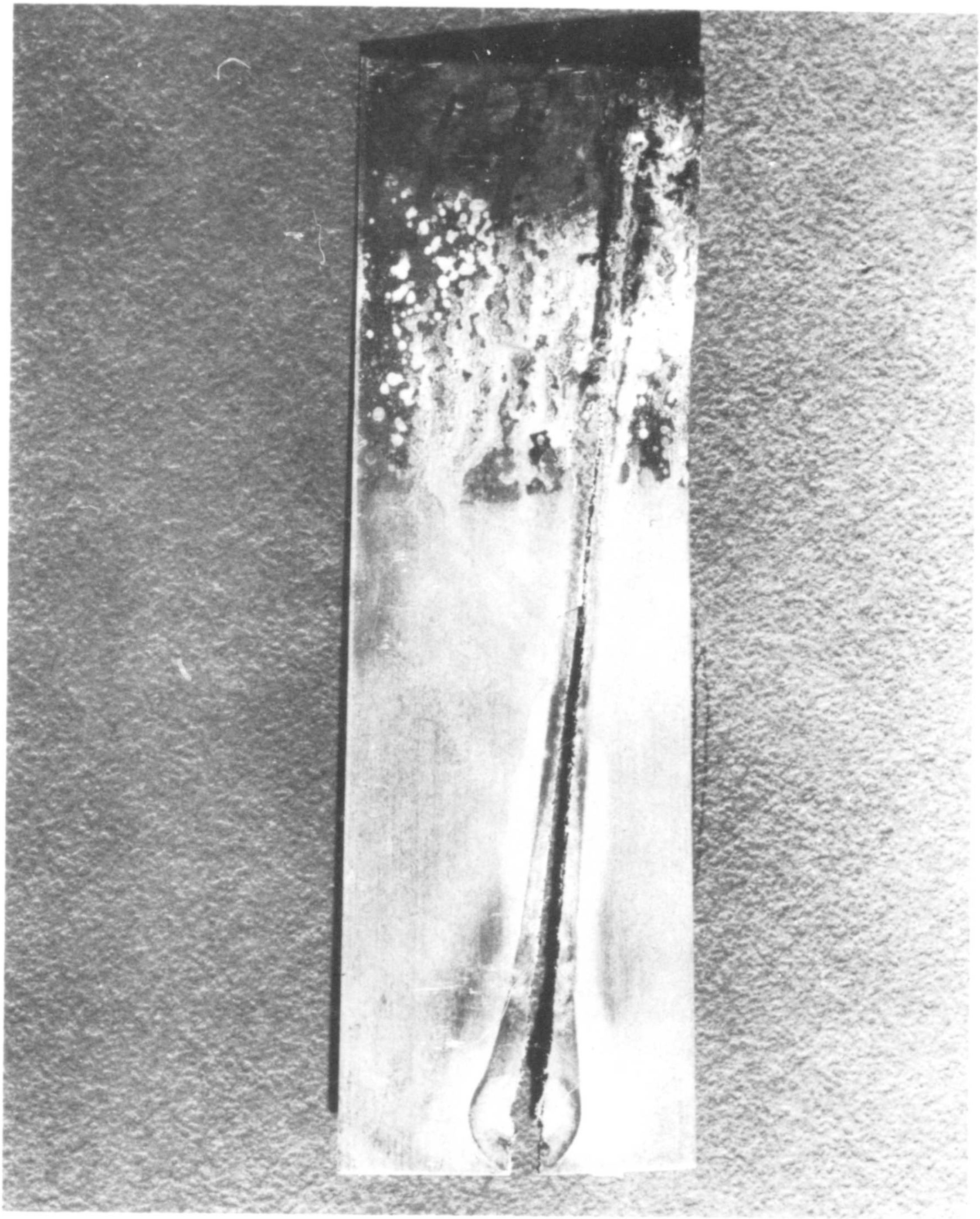

Figure A9. Sample No. 11

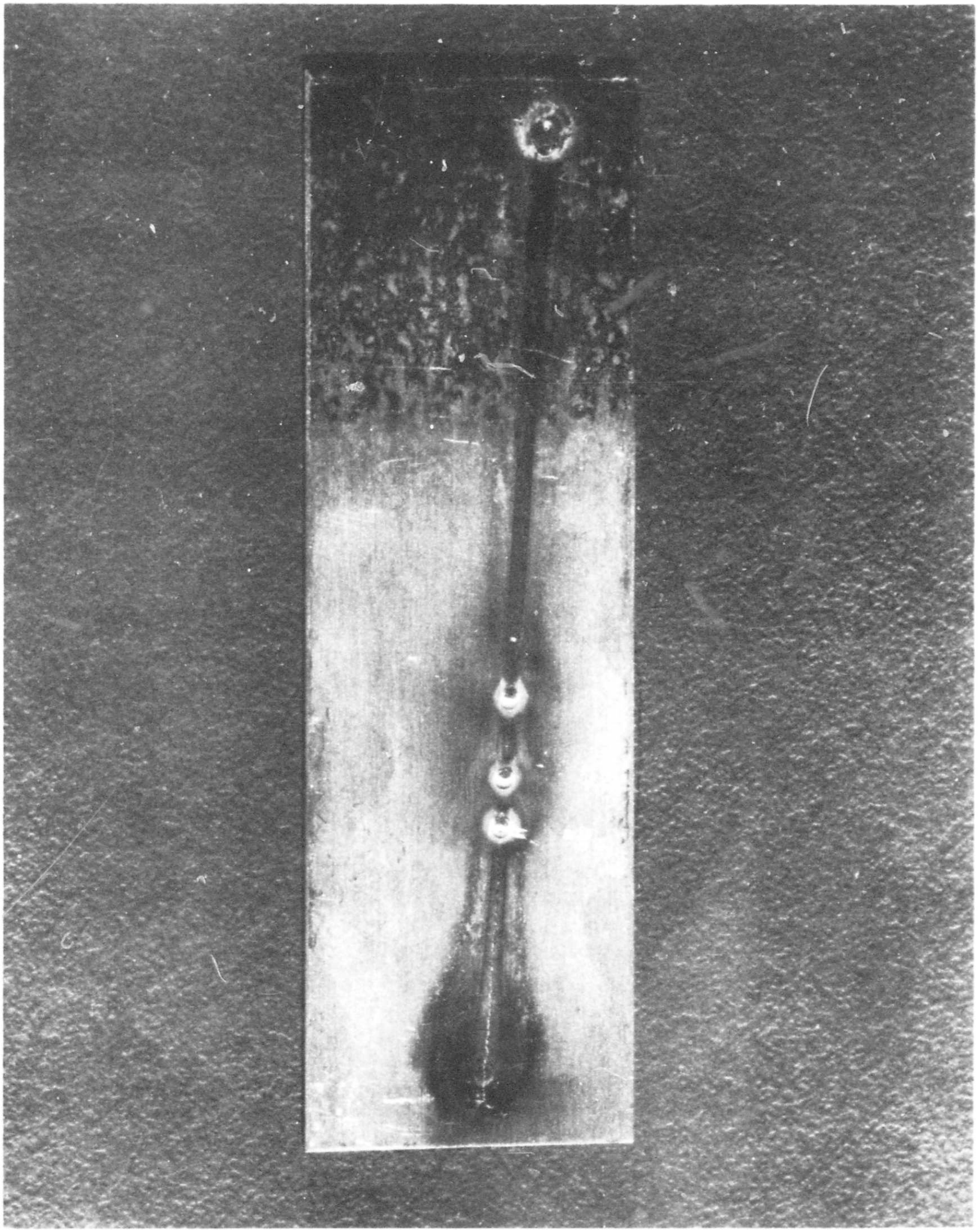

Figure A10.   Sample No. 13

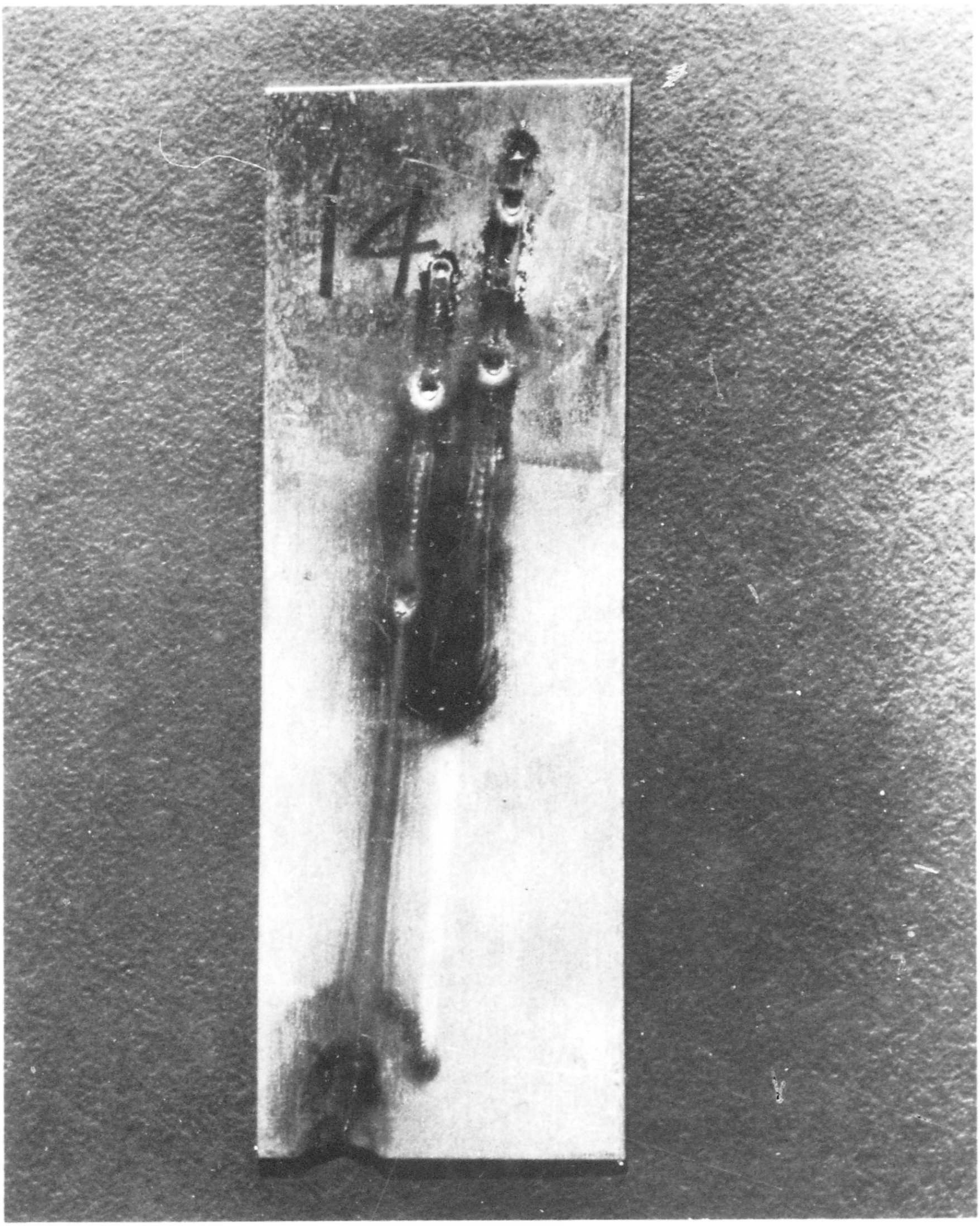

Figure A11.   Sample No. 14

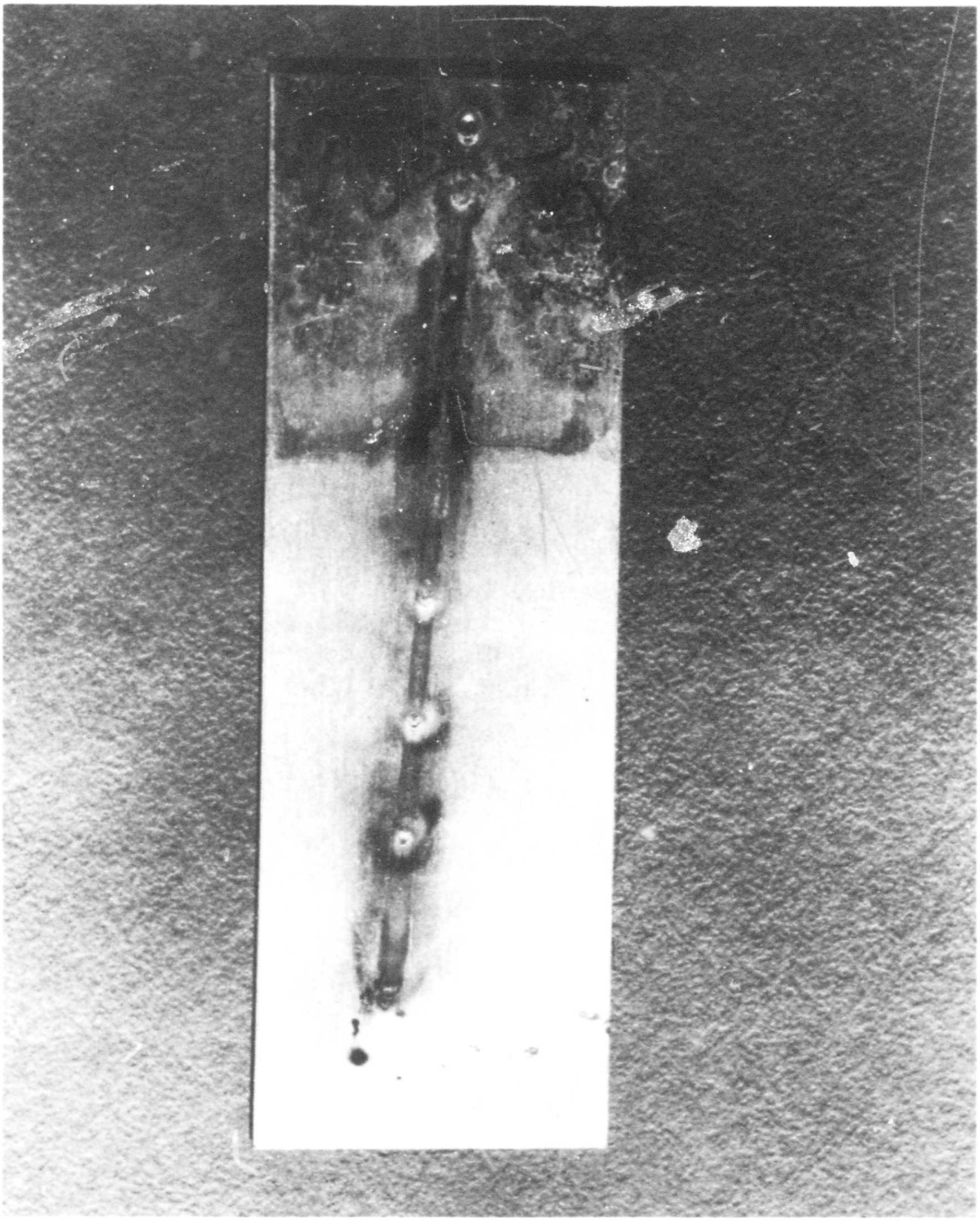

Figure A12. Sample No. 15

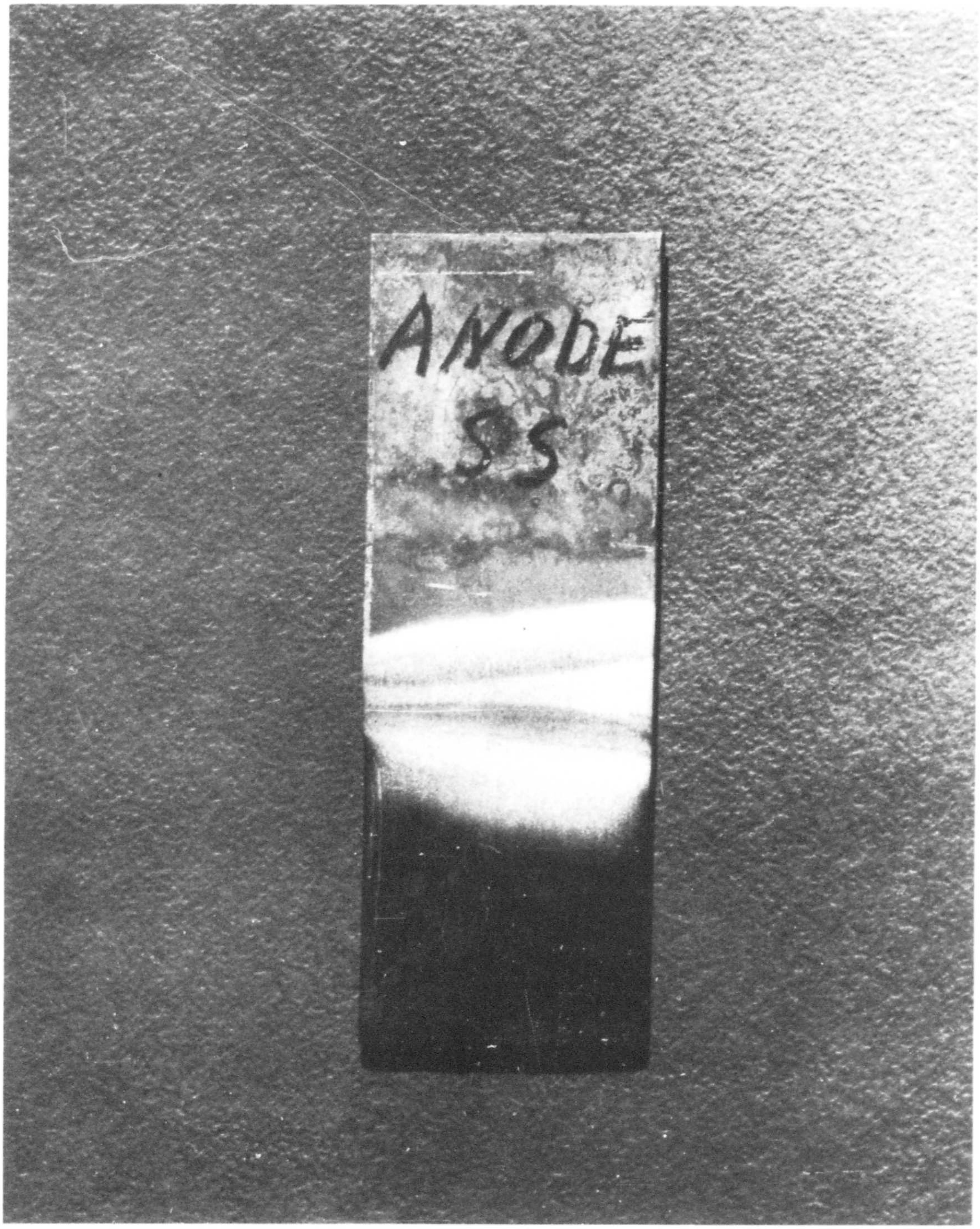

Figure A13. Sample No. 16

Figure A14. Tungsten-Arc Weld, dc, on E-130R2 Bomblet Without Filler-Metal Addition

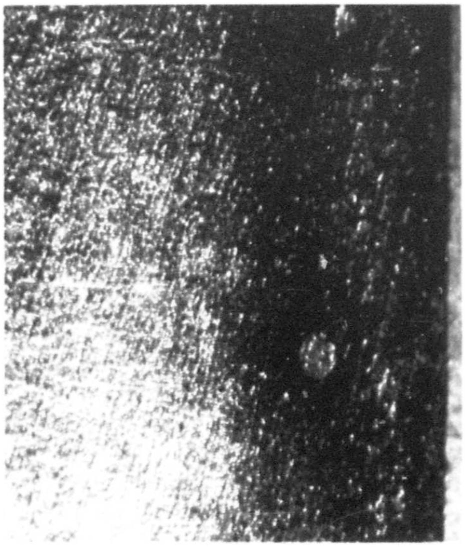

Figure A15. Surface of E-130R2 Bomblet Body

Figure A16. Surface of E-130R2 Bomblet Body

Figure A17. Tungsten-Arc Weld, dc, on E-130R2 Bomblet Without Filler-Metal Addition

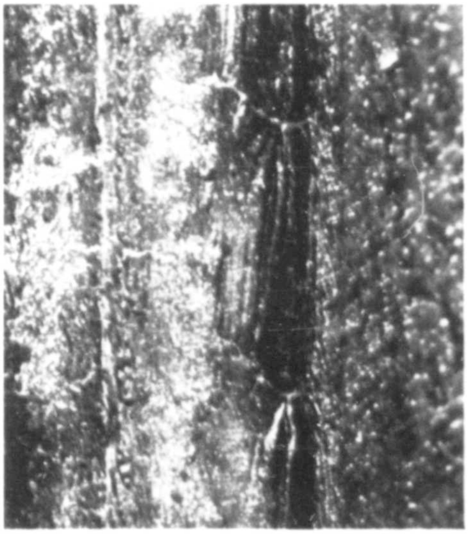

Figure A18. Tungsten-Arc Weld, dc, on E-130R2 Bomblet Without Filler-Metal Addition

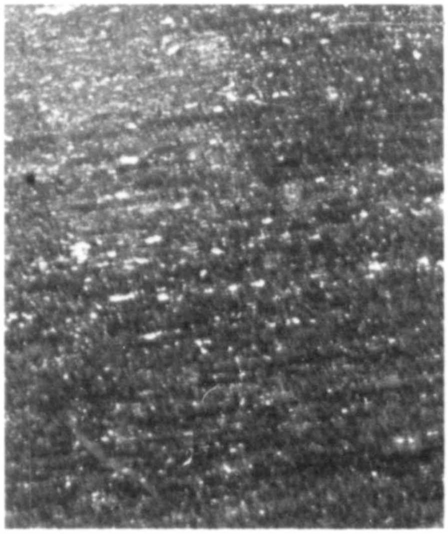

Figure A19. Surface of E-130R2 Bomblet Body

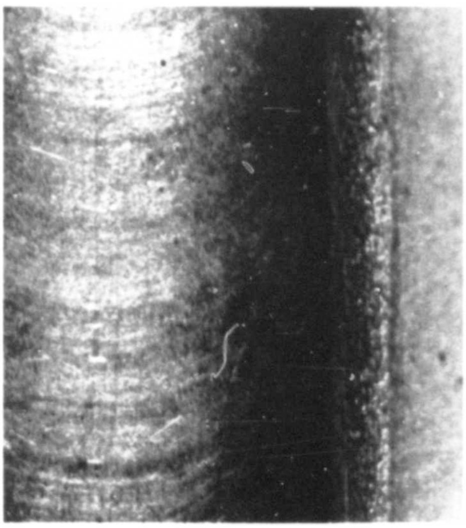

Figure A20. Tungsten-Arc Weld, ac, on E-130R2 Bomblet With Addition of 4043 Filler Metal

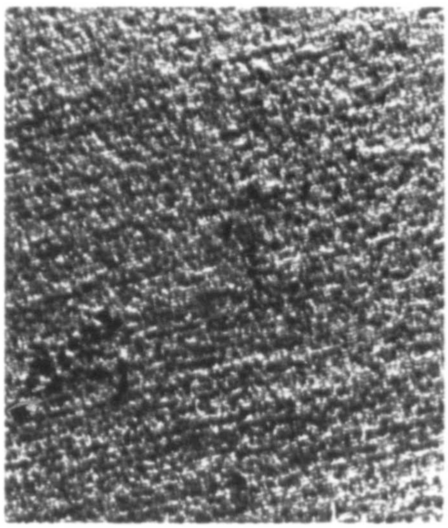

Figure A21. Surface of Bomblet Body

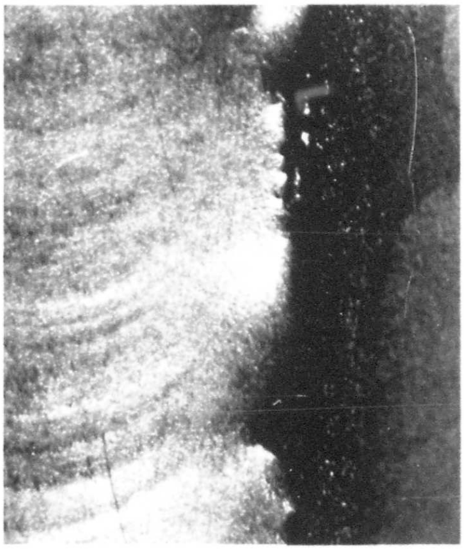

Figure A22. Tungsten-Arc Welds, dc and ac

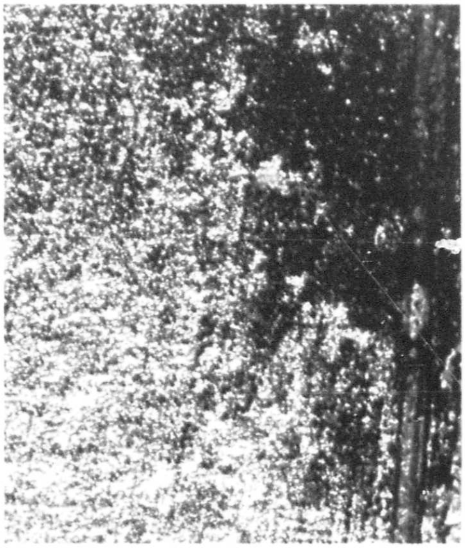

Figure A23. Area Adjacent to Weld Made in Figure A22

Figure A24. Internal View of Sectionalized E-139 Bomblet

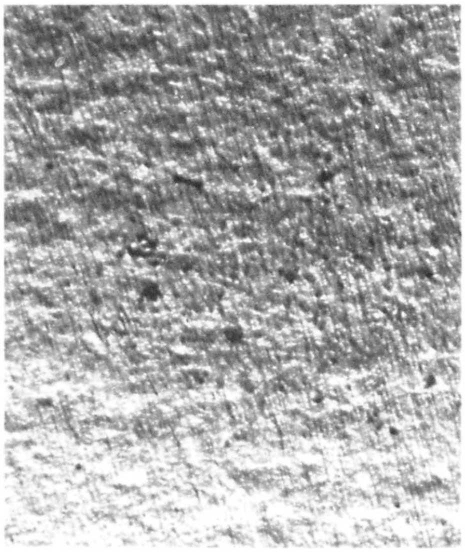

Figure A25. Surface of Welded Bomblet Body (same Bomblet shown in Figure A24)

Figure A26. Automatic ac Tungsten-Arc Weld of E-139 Bomblet

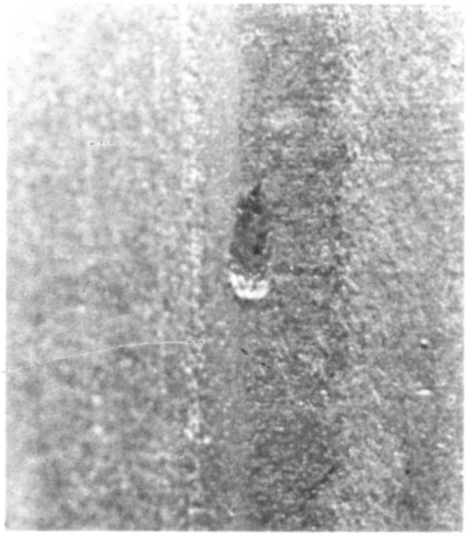

Figure A27. Surface of Welded Bomblet Body in Figure A26

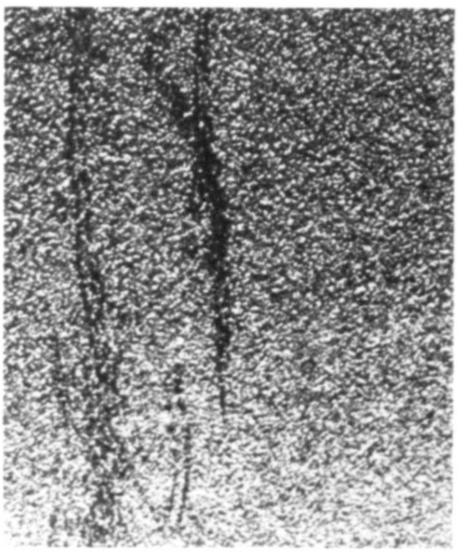

Figure A28. Surface of E-139 Bomblet Body

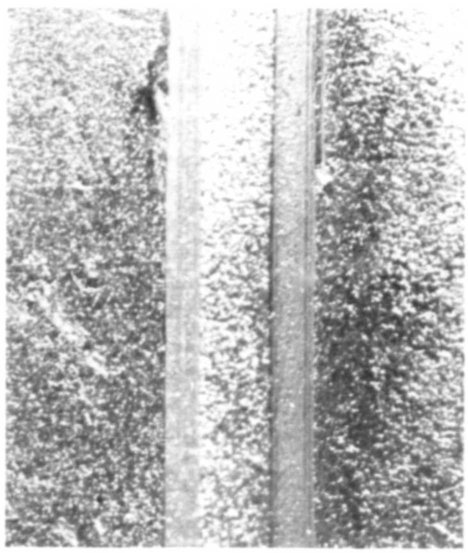

Figure A29. E-139 Bomblet Assembled for Welding

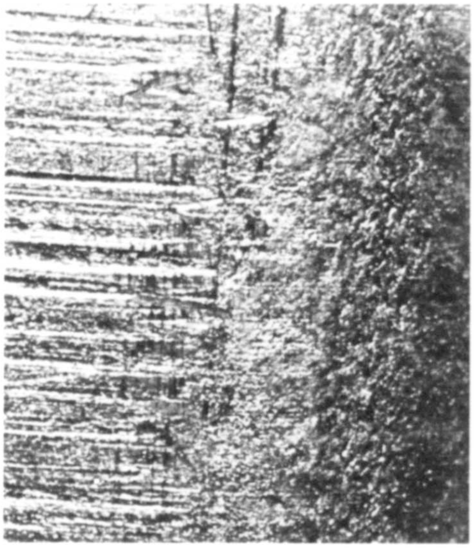

Figure A30. Surface of E-139 Bomblet Half

Figure A31. Surface of E-139 Bomblet Half

Figure A32. Surface of E-139 Bomblet Half

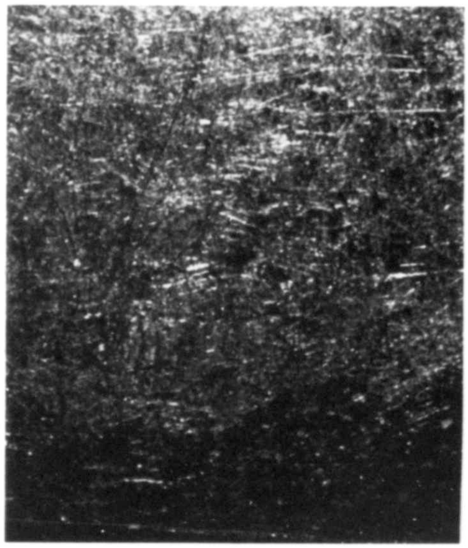

Figure A33. Surface and Edge to be Welded of E-139 Bomblet

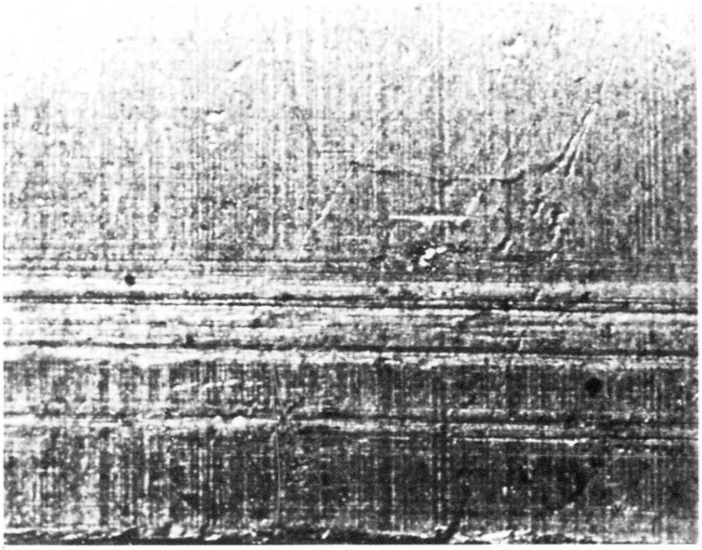

Figure A34. Surface and Edge to be Welded of E-139 Bomblet

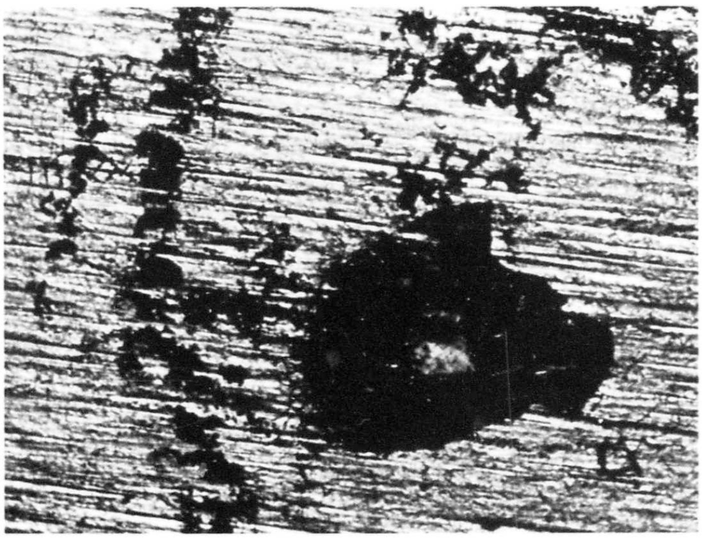

Figure A35. E-139 Bomblet After Storage Tests

Figure A36. E-139 Bomblet After Storage Tests

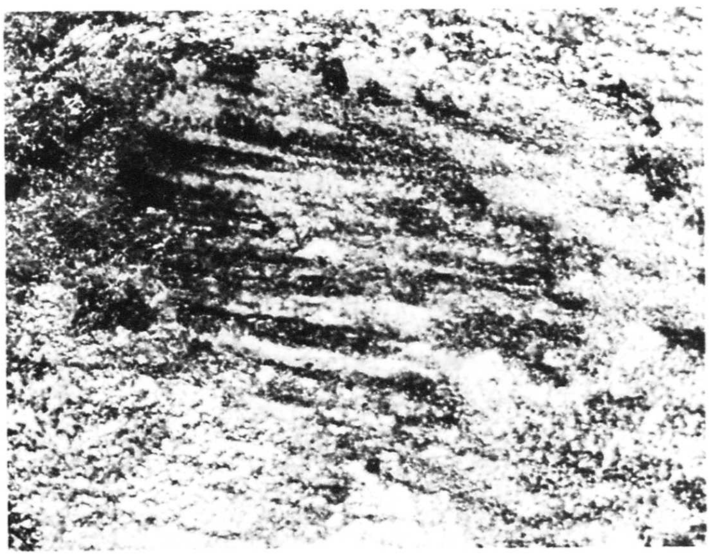

Figure A37. E-139 Bomblet After Storage Tests

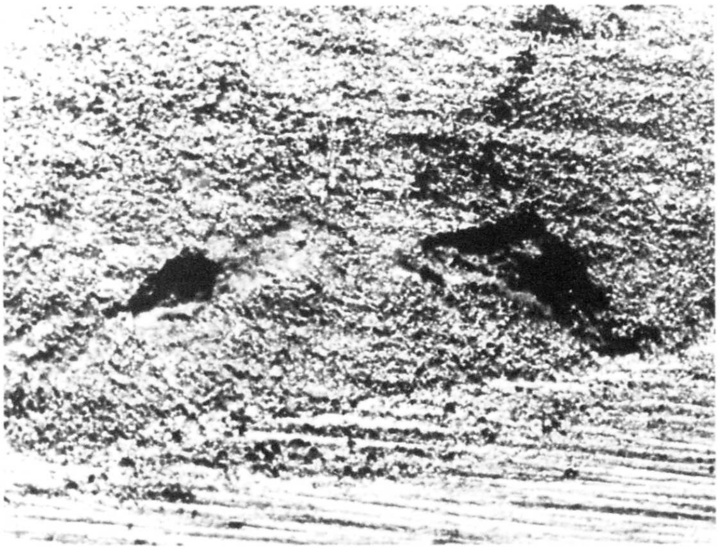

Figure A38. E-139 Bomblet After Storage Tests

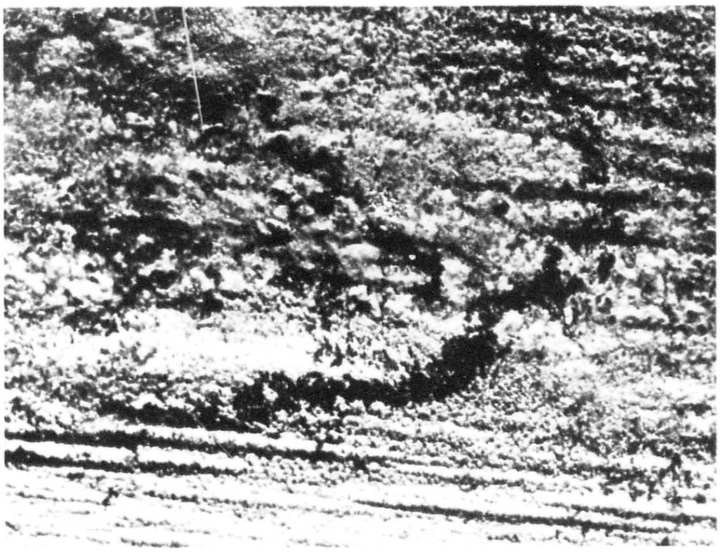

Figure A39. E-139 Bomblet After Storage Tests

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) US Army Edgewood Arsenal, Edgewood Arsenal, Maryland 21010 Preproduction Evaluation Division	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b GROUP N/A

3. REPORT TITLE
CATHODIC CLEANING OF ALUMINUM ALLOYS FOR X-RAY CLEAR WELDS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
The work was started in February 1965 and it is continuing.

5. AUTHOR(S) (Last name, first name, initial)
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13. ABSTRACT
The problem of producing an X-ray clear weld lies in the ability to remove $Al_2O_3 \cdot H_2O$ (aluminum hydrate) from the surfaces inside, outside or at the joint, as any hydrate near the welding arc disassociates and produces nascent hydrogen. The nascent hydrogen is absorbed quite readily by the aluminum materials in the solidus state and upon cooling migrates to the last point of freezing forming voids of numberous sizes, configurations and at random depth levels. The present method of cleaning after the standard chemical cleaning is to mechanically scrap and draw file all surfaces subjected to fusion, which is an art and has not been reduced to a science. The preliminary tests using cathodic cleaning conducted on 6061 aluminum strips and evaluated by welding with automatic direct current tungsten arc process shows a very definite impovement over previous cleaning methods.

14. KEYWORDS

Welding	Migrates	Cathodic cleaning
Chemical cleaning	Mascent hydrogen	X-ray clear welding
Aluminum hydrate		